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The first Forbush decrease of solar cycle 24

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Abstract. The first significant Forbush decrease of solar cycle 24 was recorded in February 18, 2011 from neutron monitors around the world. This was the result of the coronal mass ejections (CMEs) that was released from the Sun on 14 and 15 February 2011, respectively, and their interplanetary counterparts (ICME) that were prevalent in the interplanetary space in this period. We report on the global characteristics of cosmic rays during the FD such as the amplitude (A_0), the decrement and the three dimensional anisotropy parameters (A_x , A_y and A_z), deduced from the global survey method (GSM). We also analyze the interplanetary space solar wind data and we present the structure of the ICME as it passed through the Earth resulting in a strong Forbush decrease. We compare high time resolution neutron monitor data with multipoint space-based measurements of the interplanetary space (e.g. ACE/SWEPAM and ACE/MAG).

1. Introduction

Non-recurrent Forbush decreases (FDs) are defined as sudden decreases of the recorded galactic cosmic ray (GCRs) intensity, following the passage of the interplanetary counterparts of a coronal mass ejection (ICME) by Earth. The decrease typically lasts for less than one day while the recovery phase may last for several days [1]. The study of FDs is fundamental for both the understanding of the interplanetary medium and for the propagation of the cosmic ray particles through the medium itself [2]. FDs have been regularly detected at Earth by ground-based detectors as neutron monitors (NMs) shortly after major solar events. Since the 1950s a worldwide network of standardized cosmic ray detectors has been developed to examine temporal and spatial variations in the space environment. Despite decades of progress, ground-based neutron monitors (NMs) remain the state-of-the-art instrumentation for measuring cosmic rays with GeV energies, which cannot be measured in the same simple, inexpensive, and statistically accurate way by space experiments. Therefore, the worldwide network perfectly complements cosmic ray observations in space and it is useful for the identification of FDs and the study of their characteristics [3]. These events are currently considered to result from the exclusion of GCRs due to strong interplanetary magnetic field (IMF) structures at the interplanetary (IP) shock, the sheath region and/or the ejecta (usually including a magnetic cloud structure) [4,5,6,7,8]. In this work, the first significant Forbush decrease of solar cycle 24 which was recorded on 18 February 2011 from NMs around the world is studied.

2. Background of the event

After a long period of quiescent solar activity, an intense solar X-ray flare (X2.2) occurred on 15 February 2011 at 01:44UT in active region (AR) 11158, located in the south-central part of the solar disk, facing Earth [9, 10]. This has been the first X-class solar flare since December 2006 [11] and was accompanied by large plasma emissions. A coherent overview of the solar recordings by various instruments at different satellites is presented in Fig. 1. The background of this figure presents the actual position of the Earth, which corresponds to the recordings of the Solar and Heliospheric Observatory (SOHO) and the Advanced Composition Explorer (ACE) at L1 and the angular separation between the Solar TERrestrial RELations Observatory (STEREO) A and STEREO B was 179.1° in the event under investigation. The Atmospheric Imaging Assembly (AIA) at 304 \AA , onboard the Solar Dynamical Observatory (SDO) has been used for the representation of the solar flare, which is the clear brightening, spotted on the Sun on 15 February 2011. The Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI) package on board each STEREO spacecraft includes an extreme ultraviolet imager (EUVI) and a white-light coronagraph. In Fig.1 we identify the coronal mass ejection (CME) that has been recorded by both STEREO coronagraphs at 02:05 UT [12], as this seems to be the most relevant event, out of the five CMEs that have been included in the preliminary CME SECCHI catalogue because it corresponds to the SOHO/LASCO recordings of a halo CME on 15 February 2011 at 02:24 UT with a linear speed of 669 Km/sec . In STEREO CME related figures the embedded figure represents the corresponding EUVI recordings. One should also note the halo CME on the 14 February 2011 with a linear speed of 326 Km/sec , which was also spotted by both STEREO A & B coronagraphs [12] and contributed to the background level of turbulence on which the events of 15 February 2011 propagated.

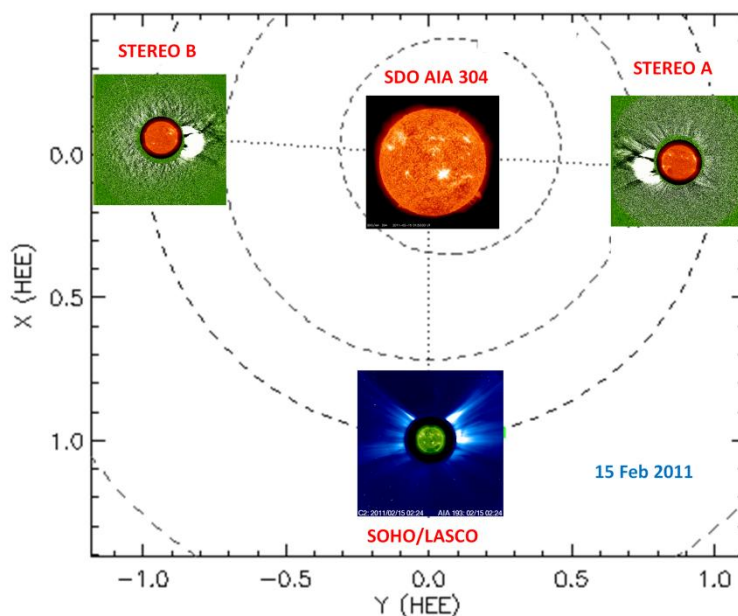


Figure 1. Situation in the near Earth space as recorded by STEREO-A, STEREO-B, SOHO/LASCO and SDO at 15 February 2011

3. Cosmic ray activity

The emitted plasma traveled through the IP space and on 18 February 2011 a simultaneous FD was recorded at NMs around the world [13]. The sudden storm commencement (SSC) identifies itself with the arrival of the ICME shock and it is marked on 18 February 2011 at 01:36 UT, in ACE/SWEPAM and ACE/MAG available data [14]. After the shock, the solar wind speed exceeds 700 km/s and IMF magnitude reaches 30 nT (Fig. 2). Clear signatures of an ICME are recorded from 18 February 2011 at 19:00 UT to 20 February 2011 at 08:00 UT [15]. This ICME is related to the halo CME that was released on 15 February 2011. The STEREO ICME list, surprisingly, does not include any ICME recordings at either STEREO spacecraft [16]. However, given the timing of the CMEs on both STEREOs and SOHO/LASCO it is very much possible to propose that it is the same event, seen by different instruments at different parts of the heliosphere. In this sense, Fig. 1, demonstrates the solar events registered on 15 February 2011 and the availability of multiple datasets which drives the pinpointing of the characteristics of the FD that occurred on 18 February 2011.



Figure 2. From top to bottom: SW temperature and density; SW speed; IMF and its components; CRs density variations A0 (red line); anisotropy (blue histogram); Dst (nT) and Kp recordings.

The cosmic ray (CR) density variations A_0 (%) and cosmic ray diurnal anisotropy A_{xy} , derived by the world wide neutron monitor network using the global survey method are presented in the lower panel of Fig. 2. One can witness the rapid decrease and gradual recovery of the FD. The magnitude of the FD A_0 was 4.7% for 10 GV particles and the anisotropy A_{xy} remained at low levels $< 1\%$ (Fig. 2). It is evident that the FD started with the shock arrival on 18 February 2011 at 01:36 UT, while the decreasing phase lasted almost 10 hours, thereafter the slow recovery phase took over. At ~04:00 UT there is another apparent decrease marked in the CR behavior. It coincides with a strong magnetic field with smooth rotation, a declining proton density and low temperature which does not last up to the minimum of the CR density.

4. Discussion

The FD of 18 February 2011 has been detected by all NMs around the world. It is not a classical two-step FD [5], probably due to the interaction of the slow CME on 14 February 2011 and the following faster CME the next day. The first step is caused by the shock and the second one is caused by the entry into the extended sheath region. When finally, CRs entered the enhanced and closed (given the bi-directional recorded electrons) magnetic field of the ejecta, the recovery phase of the decrease was already in progress.

The magnetic cloud following the shock presented a strong magnetic field but its B_z component was northward and therefore restricted the transfer of energy from the ICME into the Earth's magnetic field. As such, the geomagnetic activity level following the SSC has been relatively weak ($Dst = -40$ nT; $K_p = 4+$), leading to active conditions.

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